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Circular No. 12.

United States Department of Agriculture,

DIVISION OF FORESTRY.

SOUTHERN PINE—MECHANICAL AND PHYSICAL PROPERTIES.

The following results of the timber investigations carried on by the Division of Forestry in the laboratory at St. Louis under Prof. J. B. Johnson, and in the laboratory at Washington, by Mr. Filibert Roth, are published in condensed form in advance of a fuller account in order to make the information more speedily available. The data contained in this circular are condensed from not less than 20,000 tests, and a similarly large number of measurements and weighings, fuller details of which will appear in a special bulletin.

The chief points of superiority of the data obtained in these investigations lie in (1) correct identification of the material, it being collected by a competent botanist in the woods; (2) selection of representative trees with record of their age, development, place where grown, etc.; (3) determination of moisture conditions of the test pieces, the most influential factor on strength; (4) large number of trees and of test pieces from each tree; (5) employment of large and small sized test material from the same trees; (6) uniformity of method for an unusually large number of tests.

THE MATERIAL UNDER CONSIDERATION.

The importance of reliable information regarding the pines of the South is evident from the fact that they furnish the bulk of the hard pine material used for constructive purposes with an annual cut hardly short of 7,000,000,000 feet, B. M., which with the decline of the soft pine supplies in the North is bound to increase rapidly.

Although covering the largest area of coniferous growth in the country (about 230,000 square miles), proper economies in their use are nevertheless most needful, since much of this area is already severely culled and the cut per acre has never been very large. Hence the demonstration (a result of the investigations in this Division) that bled pine is as strong and useful as unbled, and the assurance that longleaf pine is in the average 25 per cent stronger than it is often supposed to be and, therefore, can be used in smaller sizes than customary at present, must be welcome as permitting a saving in forest resources which may readily be estimated at from eight to ten million dollars, annually, due to this information.

The pines under consideration, often but imperfectly distinguished by consumers in name or substance, are:

(1) The longleaf pine (*Pinus palustris*) also known as Georgia, or yellow, pine, and in England as "pitch pine," and by a number of other names, is to be found in a belt of 100 to 150 miles in width along the Atlantic and Gulf coasts from North Carolina to Texas, furnishing over 50 per cent of the pine timber cut in the South —the timber par excellence for heavy construction, but also useful for flooring and in other directions, where strength and wearing qualities are required.

(2) The Cuban pine (*Pinus heterophylla*), found especially in the southern portions of the longleaf pine belt, known to woodsmen commonly as "slash pine" but not distinguished in the lumber market. It is usually mixed in with longleaf, which it closely resembles although it is wider ringed (coarse grained), and to which it is equal if not superior in weight and strength.

(3) The shortleaf pine (*Pinus echinata*), also known besides many other names as yellow pine, and as North Carolina pine, but growing through all the Southern States generally north of the longleaf pine region; much softer and with much more sapwood than the former two, useful mainly, for small dimensions and as finishing wood, being about 20 per cent weaker than the longleaf pine.

(4) The loblolly, or oldfield pine (*Pinus tæda*), of similar although more southern range than the shortleaf, also known as Virginia pine, much used locally and in Washington and Baltimore, destined to find more extensive application. At present largely cut together with shortleaf and sold with it as "yellow pine," or North Carolina pine, without distinction, although sometimes far superior, approaching longleaf pine in strength and general qualities.

The names in the market are often used interchangeably and the materials in the yard mixed. All four species grow into tall but slender trunks, as a rule not exceeding 30 inches in diameter and 100 feet in height; the bulk of the logs cut at present fall below 20 inches. The sapwood forms in old trees of longleaf (with 2 to 4 inches) about 40 per cent of the total log volume; in Cuban, shortleaf, and loblolly 60 per cent and over.

A reliable microscopic distinction of the wood of the four species has not yet been found. As a rule longleaf contains much less sapwood than the other three. The narrow-ringed wood of longleaf (averaging 20 to 25 rings to the inch) usually separates it also from the other three, while the especially broad ringed Cuban excels usually also by broader summerwood bands. In the log, shortleaf and loblolly may usually be recognized as distinguished from the former by the greater proportion of sapwood and lighter color due to smaller proportion of summerwood. The general appearance of the wood of all four species is, however, quite similar. The annual rings (grain) are sharply defined, the light yellowish springwood and the dark orange-brown summerwood of each ring being strongly contrasted produce a pronounced pattern, which although pleasing especially in the curly forms, which occur occasionally, may become obtrusive when massed.

The following diagnosis may prove helpful in the distinction of the wood:

Diagnostic features of the wood.

Name of species.	Longleaf pine (*Pinus palustris* Miller)	Cuban pine (*Pinus cubensis* Griseb.).	Shortleaf pine *Pinus echinata* Miller).	Loblolly pine (*Pinus tæda* Linn).
Specific gravity of kiln-dried wood. Possible range	.50 to .90	.50 to .90	.40 to .80	.40 to .80
Specific gravity of kiln-dried wood. Most frequent range	.55 to .65	.55 to .70	.45 to .55	.45 to .55
Weight, pounds per cubic foot, kiln-dried wood. Average	36	37	30	31
Character of grain seen in cross section	Fine and even; annual rings quite uniformly narrow; on large logs averaging generally 20 to 25 rings to the inch.	Variable and coarse, rings mostly wide; averaging on large logs 10 to 20 rings to the inch.	Very variable; medium, coarse; rings wide near heart, followed by zone of narrow rings; not less than 4 (mostly about 10 to 15) rings to the inch, but often very fine-grained.	Variable, mostly very coarse; 3 to 12 rings to the inch, generally wider than in the shortleaf.
Color, general appearance	Even dark reddish-yellow to reddish-brown.	Dark straw-color with tinge of flesh-color.	Whitish to reddish or yellowish-brown.	Yellowish to orange-brown.
Sapwood, proportion	Little; rarely over 2 to 3 inches or radius.	Broad; 3 to 6 inches	Commonly over 4 inches of radius.	Very variable, 3 to 6 inches of the radius.
Resin	Very abundant; parts often turning into "light wood;" pitchy throughout.	Abundant, sometimes yielding more pitch than longleaf; "bleeds" freely, yielding little scrape.	Moderately abundant, least pitchy; only near stumps, knots, and limbs.	Abundant; more than shortleaf, less than longleaf and Cuban, but does not "bleed" if tapped.

The sapling timber of all four species is coarse grained, that of loblolly exceeding the rest in this respect. The grain varies most in the butt, least in the top, is very fine in the outer portions of all old trees. Loblolly in the center of the log frequently shows rings over one-half inch wide, and timber averaging 8 rings to the inch is not rare, while shortleaf will average 10 to 15 rings to the inch. The greater or less proportion of the sharply defined dark colored bands of summerwood of the ring furnish the most reliable and ready means of determining quality.

At present distinction is but rarely made in the species and in their use; all four species are used much alike although differentiation is very desirable on account or the difference in quality. Formerly these pines except for local use, were mostly cut or hewn into timbers, but especially since the use of dry kilns has become general and the simple oil finish has displaced the unsightly painting and "graining" of wood, southern pine is cut into every form and grade of lumber. Nevertheless a large proportion of the total cut is still being sawn to order in sizes above 6 by 6 inches, and lengths above 20 feet for timbers, for which the longleaf and Cuban furnish ideal material. The resinous condition of these two pines make them also desirable for railway ties of lasting quality.

MECHANICAL PROPERTIES.

In general the wood of all these pines is heavy for pine (31 to 40 pounds per cubic foot, when dry) soft to moderately hard (hard for pine) requiring about 1,000 pounds per square inch to indent one-twentieth inch; stiff, the modulus of elasticity being from 1,500,000 upward; strong, requiring from 7,000 pounds per square inch and upward to break in bending and over 5,000 pounds in compression when yard-dry.

The values given in this circular are averages based on a large number of tests from which only defective pieces are excluded.

In all cases where the contrary is not stated the weight of the wood refers to kiln-dried material and the strength to wood containing 15 per cent moisture, which may be conceived as just on the border of air-dried condition. The first table gives fairly well the range of strength of commercial timber.

Average strength of Southern pine.

Air-dry material (about 15 per cent moisture).

Name.	Compression strength. With grain. Average of all valid tests. Absolute.	Rela-tive.	Compression strength. With grain. Average for the weakest one-tenth of all the tests. Absolute.	Rela-tive.	Compression strength. Across grain. 3 per cent. indentation.	Bending strength. At rupture modulus $\frac{3\,Wl}{2\,bh^2}$. Average of all valid tests. Absolute.	Rela-tive.	Bending strength. At rupture modulus $\frac{3\,Wl}{2\,bh^2}$. Average for the weakest one-tenth of all the tests. Absolute.	Rela-tive.	Bending strength. At elastic limit modulus $\frac{3\,W_1 l}{2\,bh^2}$	Elasticity (stiffness) modulus $\frac{3\,Wl^3}{4\,\Delta\,bh^3}$	Relative elastic resilience.	Tensile strength.	Shearing strength.
	Lbs. per sq. inch.		*Lbs. per sq. inch.*		*Lbs. per sq. inch.*	*Lbs. per sq. inch.*		*Lbs. per sq. inch.*		*Lbs. per sq. inch.*	*Lbs. per sq. inch.*	*In.-lbs. per cu. in.*	*Lbs. per sq. inch.*	*Lbs. per sq. inch.*
Cuban pine	7,850	100	6,500	100	1,050	11,950	100	8,750	100	9,450	2,305,000	2.5	14,300	680
Longleaf pine	6,850	87	5,650	87	1,060	10,900	91	8,800	101	8,500	1,890,000	2.3	15,200	706
Loblolly pine	6,500	83	5,350	82	990	10,100	84	8,100	92	8,150	1,950,000	2.25	14,400	690
Shortleaf pine	5,900	75	4,800	74	940	9,230	77	7,000	80	7,200	1,600,000	2.05	13,400	688

RELATION OF STRENGTH TO WEIGHT.

The intimate relation of strength and specific weight has been well established by the experiments. The average results obtained in connection with the tests themselves were as follows:

	Cuban.	Longleaf.	Loblolly.	Shortleaf.
Transverse strength	100	91	84	77
Specific weight of test pieces	100	94	82	77

Since in the determination of the specific gravity above given, wood of the same per cent of moisture (as is the case of the values of strength), was not always involved, and also since the test pieces, owing to size and shape, can not perfectly represent the wood of the entire stem, the following results of a special inquiry into the weight of the wood represents probably more accurately the weight and with it the strength-relations of the four species.

WEIGHT RELATIONS.

[These data refer to the average speeifie weight for all the wood of each tree, only trees of approximately the same age being involved.]

Name.	Cuban.	Longleaf.	Loblolly.	Shortleaf.
Average age of trees	171	127	137	131
Number of trees involved	6	22	14	10
Specific gravity of dry wood	0.63	0.61	0.53	0.51
Weight per cubie foot	39	38	33	32
Relative weight	100	97	84	81
(Transverse strength *)	(100)	(91)	(84)	(77)

* The values of strength refer to all tests and therefore involve trees of wide range of age and consequently of quality, especially those of longleaf, involve much wood of *old* trees, hence the relation of weight and strength appears less distinct.

From these results, although slightly at variance, we are justified in concluding that Cuban and longleaf pine are nearly alike in strength and weight and excel loblolly and shortleaf by about 20 per cent. Of these latter, contrary to common belief, the Loblolly is the heavier and stronger.

The weakest material would differ from the average material in transverse strength by about 20 per cent and in compression strength by about 30 to 35 per cent, except Cuban pine, for which the difference appears greater in transverse and smaller in compression strength. It must, of course, not be overlooked that these figures are obtained from full grown trees of the virgin forest, that strength varies with physical conditions of the material and that, therefore, an intelligent inspection of the stick is always necessary before applying the values in practice. They can only represent the average conditions for a large amount of material.

DISTRIBUTION OF WEIGHT AND STRENGTH THROUGHOUT THE TREE.

In any one tree the wood is lighter and weaker as we pass from the base to the top. This is true of every tree and of all four species. The decrease in weight and strength is most pronounced in the first 20 feet from the stump and grows smaller upward. (See diagram 1.)

This great difference in weight and strength between butt and top finds explanation in the relative width of the summerwood. Since the specific weight of the dark summerwood band in each ring is in thrifty growth from .90 to 1.00, while that of the springwood is only about .40, the relative amount of summerwood furnishes altogether the most delicate and accurate measure of these differences of weight as well as strength, and hence is the surest criterion for ocular inspection of quality, especially since this relation is free from the disturbing influence of both resin and moisture contents of the wood, so conspicuous in weight determinations.

The following figures show the distribution of the summerwood in a single tree of longleaf pine, as an example of this relation:

	In the 10 rings next to the bark.	In the 10 rings, No 100 to 110 from bark.	Average for entire disk.	Specific weight.
	Per cent.	*Per cent.*	*Per cent.*	
At the stump	37	52	50	0.73
32 feet from stump	25	38	33	.59
87 feet from stump	15	37	26	.55

Weight and strength of wood at different heights in the tree.

	Strength of longleaf pine. (Pounds per square inch.)		Specific weight.			Mean of all three species.	Relative strength of longleaf pine.
	Bending strength.	Compression endwise. (With grain.)	Longleaf.	Loblolly.	Shortleaf.	Relative weight.	Mean of compression and bending.
Number trees used....	56		22	14	12	48	56
Average age of trees...	150 (over)		127	113	131		
No. of feet from stump:							
0			.751	.629	.614		
			106	*106*	*105*	*106*	
6	12,100	7,350	.705	.595	.585		
	100	*100*	*100*	*100*	*100*	*100*	*100*
10	11,650	7,200	.674	.578	.565		
	96	*98*	*96*	*97*	*97*	*97*	*97*
20	10,700	6,800	.624	.534	.523		
	88	*93*	*89*	*90*	*90*	*90*	*90*
30	10,100	6,500	.590	.508	.496		
	84	*89*	*84*	*86*	*85*	*85*	*86*
40	9,500	6,300	.560	.491	.472		
	79	*86*	*80*	*83*	*81*	*81*	82
50	9,000	6,150	.539	.476	.455		
	75	*83*	*77*	*80*	*78*	*78*	*79*
60	8,600	6,050	.528	.470	.454		
	71	*82*	*75*	*79*	*78*	*77*	*76*

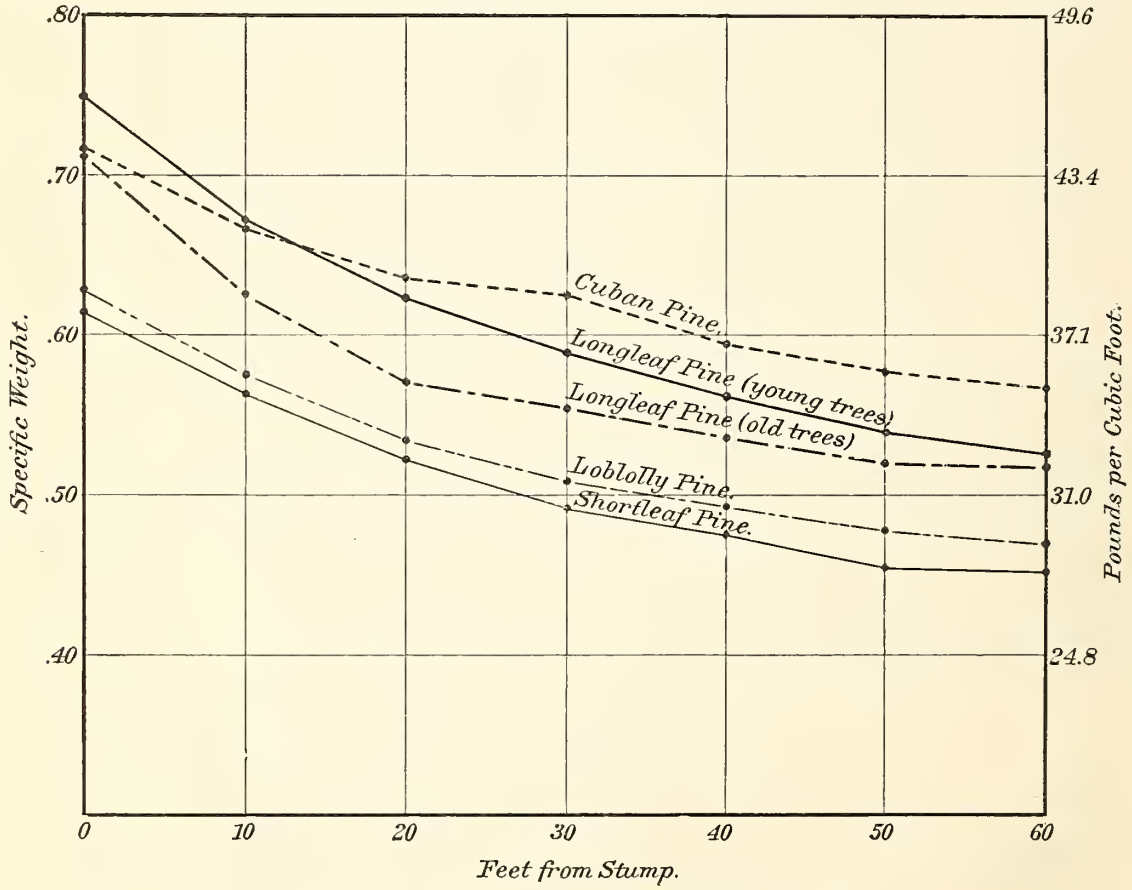

DIAGRAM 1.—Variation of weight with height of tree.

Logs from the top can usually be recognized by the larger percentage of sapwood and the smaller proportion and more regular outlines of the bands of summerwood, which are more or less wavy in the buttlogs.

The variation of weight is well illustrated in the foregoing table, in which the relative values are indicated in italics. For comparison the figures for strength of longleaf pine are added.

Both weight and strength vary in the different parts of the same cross section from center to periphery, and though the variations appear frequently irregular in single individuals, a definite law of relation is nevertheless discernable in large averages, and once determined is readily observable in every tree.

A separate inquiry, avoiding the many variables which enter in the mechanical tests, permits the following deductions for the wood of these pines, and especially for longleaf; the data referring to weight, but by inference also to strength:

1. The variation is greatest in the butt log (the heaviest part) and least in the top logs.

2. The variation in weight, hence also in strength, from center to periphery depends on the rate of growth, the heavier, stronger wood being formed during the period of most rapid growth, lighter and weaker wood in old age.

3. Aberrations from the normal growth, due to unusual seasons and other disturbing causes, cloud the uniformity of the law of variation, thus occasionally leading to the formation of heavier, broad-ringed wood in old, and lighter narrow-ringed wood in young trees.

4. Slow-growing trees (with narrow rings) do not make less heavy, nor heavier wood than thriftily grown trees (with wide rings) of the same age. (See diagram 2.)

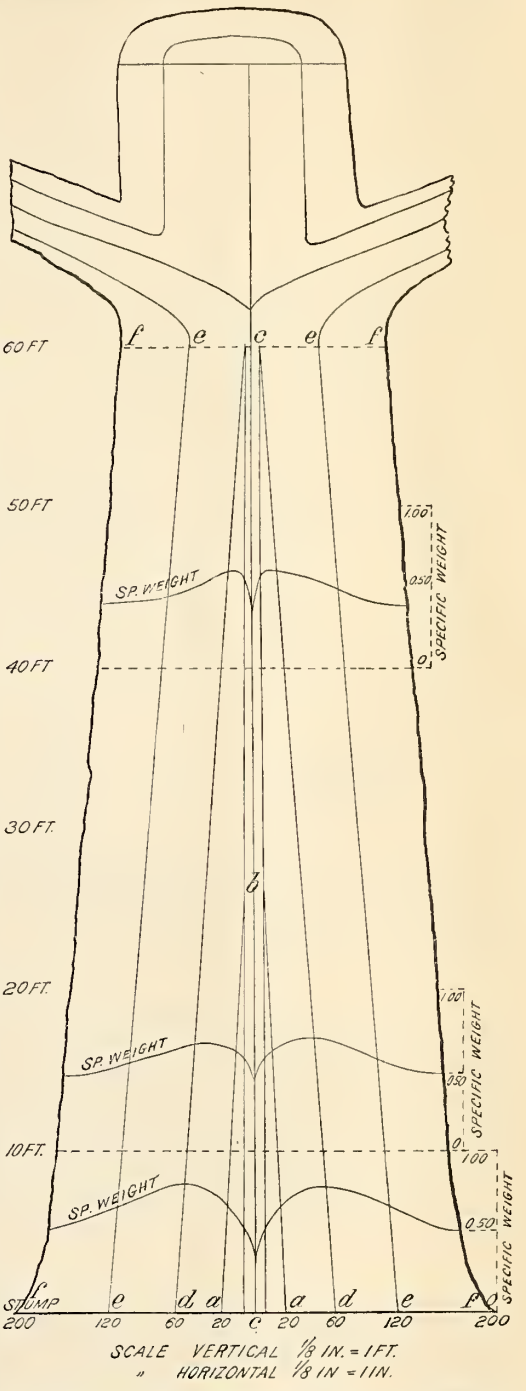

DIAGRAM 2.—Schematic section through stem of longleaf pine, showing variation of specific weight with height, diameter and age at 20 (*aba*), 60 (*dcd*), 120 (*eece*), 200 (*fffff*) years.

EFFECT OF AGE.

The interior of the butt log, representing the young sapling of less than 15 or 20 years of age, and the central portion of all logs containing the pith and 2 to 5 rings adjoining is always light and weak.

The heaviest wood in longleaf and Cuban pine is formed between the ages of 15 and 120 years with a specific weight of over .60, and a maximum of .66 to .68, between the ages of 40 and 60 years. The wood formed at the age of about 100 years will have a specific weight of .62 to .63, which is also the average weight for the entire wood of old trees; the wood formed after this age is lighter but does not fall below .50 up to the two hundredth year; the strength varies in the same ratio.

In the shorter lived loblolly and shortleaf the period for the formation of the heaviest wood is between the ages of 15 and 80, the average weight being then over .50 with a maximum of .57 at the age of 30 to 40. The average weight for old trees (.51 to .52) lies about the seventy-fifth year, the weight then falling off to about .45 at the age of 140, and continuing to decrease to below .38, as the trees grow older.

That these statements refer only to the clear portions of each log, and are variably affected at each whorl of knots (every 10 to 30 inches) according to their size, and also by the variable amounts of resin (up to 20 per cent of the dry weight) must be selfevident.

Sapwood is not necessarily weaker than heartwood, only usually the sapwood of the large sized trees we are now using is represented by the narrow-ringed outer part, which was formed during the old-age period of growth, when naturally lighter and weaker wood is made; but the wood formed during the more thrifty diameter growth of the first 80 to 100 years—sapwood at the time, changed into heartwood later—was even as sapwood the heaviest and strongest.

RANGE OF VALUES FOR WEIGHT AND STRENGTH.

Although the range of values for the individual tree of any given species varies from butt to top, and from center to periphery by 15 to 25 per cent and occasionally more, the deviation from average values from one individual to another is not usually as great as has been believed; thus of 56 trees of longleaf pine, 42 trees varied in their average strength by less than 10 per cent from the average of all 56.

The following table of weight (which is a direct and fair indication of strength), representing all the wood of the stem and excluding knots and other defects, gives a more perfect idea of the range of these values:

Range of specific weight with age (kiln-dried wood.)

[To avoid fractions the values are multiplied by 100.]

	Cuban.	Longleaf.	Loblolly.	Shortleaf.
Number of trees involved	24	96	60	56
Trees over 200 years old	61	57	—	—
Trees 150–200 years old	63	59	50	—
Trees 100–150 years old	—	60.5	53	51
Trees 50–100 years old	61	62	53 4	55
Trees 25–50 years old	55	61	53	57
Trees under 25 years old	51	55	48	53

Though occasionally some very exceptional trees occur, especially in loblolly and shortleaf, the range on the whole is generallywithin remarkably narrow limits, as appears from the following table:

Range of specific weight in trees of the same age approximately; averages for whole trees.

[Specific gravity multiplied by 100 to avoid fractions.]

Name.	No. of trees.	Age, years.	Single trees.													Average.
Cuban	4	150–200	56	68	62	65	..	..	..	..	..	..	..	..	..	62.5
	5	50–100	60	58	60	59	67	..	..	..	..	..	..	..	..	60.9
Longleaf pine	13	100–150	59	66	57	62	66	58	59	57	57	66	59	62	57	60.5
Loblolly pine	10	125–150	51	51	53	51	55	53	54	55	55	52	..	..	..	52.8
Shortleaf pine	12	100–150	45	47	53	47	50	51	55	55	53	51	50	53	..	50.8

From this table it would appear that single individuals of one species would approximate single individuals of another species so closely that the weight distinction seems to fail, but in large numbers, for instance car loads of material, the averages above given will prevail.

INFLUENCE OF LOCALITY.

In both the Cuban and longleaf pine the locality where grown appears to have but little influence on weight or strength, and there is no reason to believe that the longleaf pine from one State is better than that from any other, since such variations as are claimed can be found on any 40-acre lot of timber in any State. But with loblolly and still more with shortleaf this seems not to be the case. Being widely distributed over many localities different in soil and climate, the growth of the shortleaf pine seems materially influenced by location. The wood from the southern coast and gulf region and even Arkansas is generally heavier than the wood from localities farther north. Very light and fine grained wood is seldom met near the southern limit of the range, while it is almost the rule in Missouri, where forms resembling the Norway pine are by no means rare. The loblolly, occupying both wet and dry soils, varies accordingly.

INFLUENCE OF MOISTURE.

This influence is among the most important, hence all tests have been made with due regard to moisture contents. Seasoned wood is stronger than green and moist wood the difference between green and seasoned wood may amount to 50 and even 100 per cent. The influence of seasoning consists in (1) bringing by means of shrinkage about 10 per cent more fibers into the same square inch of cross section than are contained in the wet wood; (2) shrinking the cell-wall itself by about 50 per cent of its cross section and thus hardening it, just as a cow skin becomes thinner and harder by drying.

In the following tables and diagram this is fully illustrated; the values presented in these tables and diagrams are based on large numbers of tests and are fairly safe for ordinary use. They still require further revision, since the relations to density, etc., have had to be neglected in this study.

Influence of moisture on strength.

	Average of all valid tests.						Relative values.					
	Per cent of moisture.	Cuban.	Longleaf.	Loblolly.	Shortleaf.		Per cent of Moisture.	Cuban.	Longleaf.	Loblolly.	Shortleaf.	Average.
Bending strength.	33 per cent.*	8,450	7,660	7,370	6,900	Bending strength.	33 per cent.*	100	100	100	100	100
	20 "	10,050	8,900	8,650	8,170		20 "	118	116	117	118	117
	15 "	11,950	10,900	10,100	9,230		15 "	142	142	138	134	139
	10 "	15,300	14,000	12,400	11,000		10 "	181	182	168	160	173
Crushing endwise.	33 "	5,000	4,450	4,170	4,160	Crushing endwise.	33 "	100	100	100	100	100
	20 "	6,600	5,450	5,350	5,100		20 "	132	122	128	122	126
	15 "	7,850	6,850	6,500	5,900		15 "	157	154	156	142	152
	10 "	9,200	9,200	8,650	7,000		10 "	184	206	206	168	191
						Mean of both bending and crushing strength.	33 "	100	100	100	100	100
							20 "	125	119	122	120	122
							15 "	149	148	147	138	146
							10 "	182	194	187	164	182

* 33 per cent green, 20 per cent half dry, 15 per cent yard dry, 10 per cent room dry.

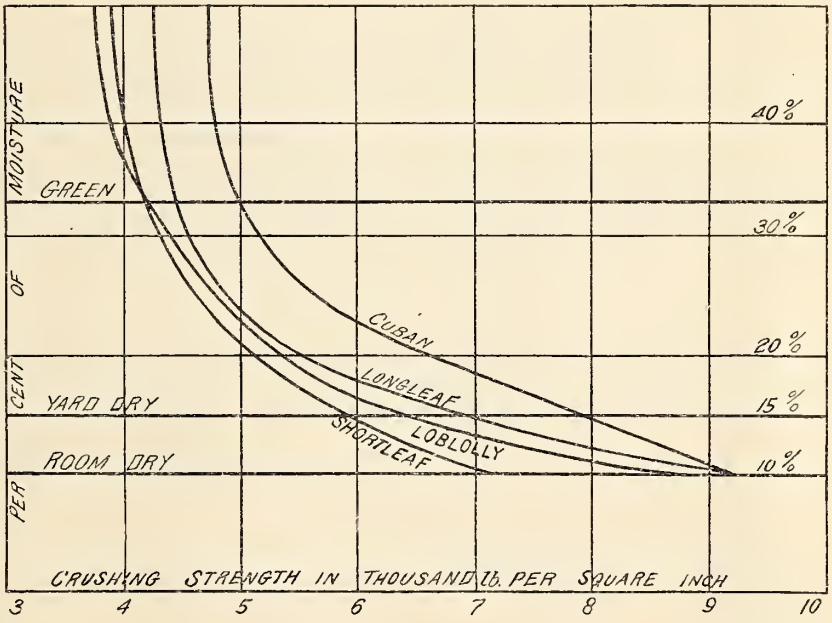

Diagram 3.—Variation of compression strength with moisture.

It will be observed that the strength increases by about 50 per cent in ordinary good yard seasoning, and that it can be increased about 30 per cent more by complete seasoning in kiln or house.

Large timbers require several years before even the yard season condition is attained but 2-inch and lighter material is generally not used with more than 15 per cent moisture.

WEIGHT AND MOISTURE.

So far the weight of only the kiln-dry wood has been considered. In fresh as well as all yard and air-dried material there is contained a variable amount of water. The amount of water contained in fresh wood of these pines forms more than half the weight of the fresh sapwood, and about one-fifth to one-fourth of the heartwood; in yard-dry wood it falls to about 12 to 18 per cent, while in wood kept in well ventilated and especially in heated rooms, it is about 5 to 10 per cent, varying with size of piece, part of tree, species, temperature and humidity of air. Heated to 150° F. (65° C.) the wood loses all but about 1½ to 2 per cent of its moisture, and if the temperature is raised to 175° F. there remains less than 1 per cent; the wood dried at 212° F. being assumed to be (though it is not really) perfectly dry. Of course large pieces are in practice never left long enough exposed to become truly kiln-dry, though in factories this state is often approached.

As long as the water in the wood amounts to about 30 per cent or more of the dry weight of the wood there is no shrinkage* (the water coming from the cell lumen) and the density or specific gravity changes simply in direct proportion to the loss of water. When the moisture per cent falls below about 30, the water comes from the cell wall, and the loss of water and weight is accompanied by a loss of volume, so that both factors of the fraction

$$\text{Specific gravity} = \frac{\text{weight}}{\text{volume}}$$

are affected and the change in the specific gravity no longer is simply proportional to the loss of water or weight. The loss of weight and volume, however, being unequal and disproportionate, a marked reduction of the specific gravity takes place, amounting in these pines to about 8 to 10 per cent of the specific weight of the dry wood.

SHRINKAGE.

The behavior of the wood of the southern pines in shrinkage does not differ materially. Generally the heavier wood shrinks the most, and sapwood shrinks about one-fourth more than heartwood of the same specific weight. Very resinous pieces ("light wood") shrink much less than other wood. In keeping with these general facts, the shrinkage of the wood of the upper logs is usually 15 to 20 per cent less than that of the butt pieces and the shrinkage of the heavy heartwood of old trees is greater than that of the lighter peripheral parts of the same, while the shrinkage of the heavy wood of saplings is greatest of all. On the whole, the wood of these pines shrinks about 10 per cent in its volume; 3 to 4 per cent along the radius, and 6 to 7 per cent along the tangent or along the yearly rings.

After leaving the kiln the wood at once begins to absorb moisture and to swell. In an experiment with short pieces of loblolly and shortleaf, representing ordinary flooring or siding sizes, these regained more than half the water and underwent over half the total swelling during the first 10 days after leaving the kiln (see diagram 4). Even in this less than air-dry wood the changes in weight far excel the changes in volume (sum of radial and tangential swelling) and, therefore, the specific gravity even at this low per cent of moisture was decreased by drying and increased by subsequent absorption of moisture. Immersion and, still more readily, boiling, cause the wood to return to its original size, but temperatures even above the boiling point do not prevent the wood from "working," or shrinking and swelling.

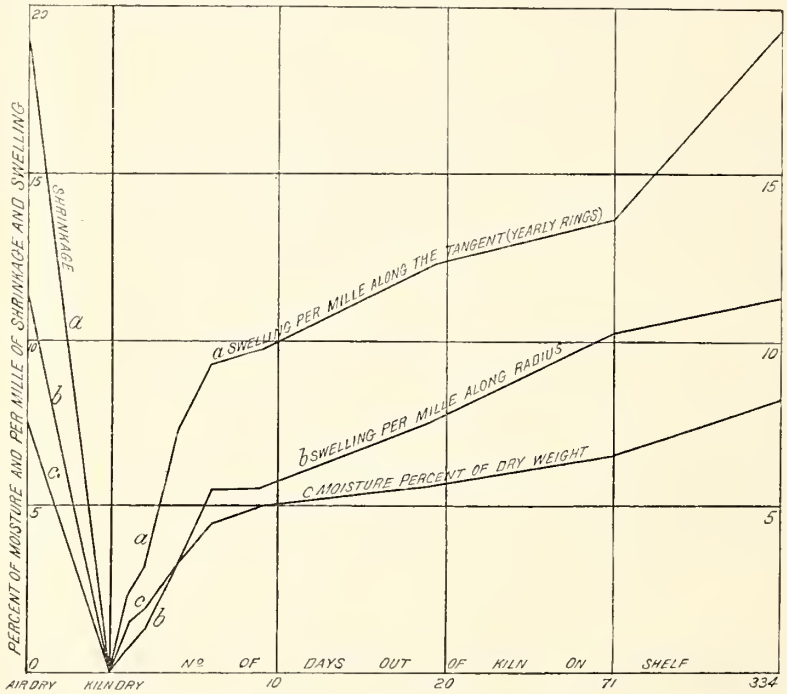

DIAGRAM 4.—Loss of water in kiln drying and reabsorption in air, skrinking and swelling.

In diagram 4 are represented the results of experiments on the rate of loss of water in the dry kiln and the re-absorption of water in the air. The wood used was of loblolly and shortleaf pine kept on a shelf in an ordinary room before and after kiln-drying. The measurements were made with caliper.

* In ordinary lumber and all large size material the exterior parts commonly dry so much sooner than the bulk of the stick that checking often occurs though the moisture per cent of the whole stick is still far above 30.

EFFECT OF KILN DRYING.

Although kiln-drying has become quite universal, opinions are still divided as to its effects upon the strength of the material and other qualities. Many objections and claims as to physical and chemical changes produced by the treatment remain unsubstantiated. The method most widely used and most severely criticized is that of the "blower" kiln, where hot air (180° F.) is forced into the drying room by means of powerful fans. Besides the many, in part, unreasonable and contradictory claims about closing or opening of pores, chemical or physical influence on the sap and its contents, albumen, gum, resin, sugar, etc., substances whose very existence in many cases is problematical or doubtful, the general claims of increased checking and warping, "casehardening," "honeycombing," etc., as well as reduction of strength, are still prevalent even among the very manufacturers themselves. The manner and progress of the kiln-drying may render this otherwise useful method of seasoning injurious. Rapid drying of the heavier hardwoods of complicated structure, especially in large sizes and from the green state, is apt to produce inordinate checking and thus weakening of the material. For Southern pine, however, it is entirely practicable to carry on the process without any injury as is evidenced by the following experiment, in which wood of Cuban pine in small dimensions (4 by 4) was seasoned in warm air (about 100° F.) and parts of the same scantling were dried at temperatures varying from 150° at the entrance end to 190° F. at the exit.

	Bending strength.		Compression strength.
	Absolute.	At elastic limit.	
	Lbs. per sq. in.	*Lbs. per sq. in.*	*Lbs. per sq. in.*
Mean of material not kiln dried (reduced to 15 per cent of moisture)	12,200	9,070	7,630
Average of kiln-dry material	11,500	9,180	8,550

Well constructed "blower kilns," where the hot air is blown in at one end and escapes at the other (this latter always the entrance end for the material) are giving satisfaction. The best kiln, however, seems to be one in which ample piping in the kiln itself insures sufficiently high (up to 180° F.), uniform temperature in all parts of the kiln, and where the circulation, promoted by a suction fan, is moderate and under perfect control. In such kilns even timbers of large size can be dried satisfactorily with a temperature not over 150° F.

EFFECT OF HIGH TEMPERATURE AND HIGH PRESSURE PROCESSES.

For some time a process employing high temperature under high pressure (temperature over 300° F., pressure 150 pounds), has been discussed and applied, claiming as a result of the treatment (1) increase in strength; (2) increase in durability; (3) absence of shrinkage.

The result of a series of experiments in which a number of scantlings of longleaf pine, one-half treated, the other untreated, is as follows:

	Bending strength.	Compression strength.
	Lbs. per sq. in.	*Lbs. per sq. in.*
Treated	7,770	5,600
Untreated	12,340	7,400

The same difference in favor of the untreated material obtained in every single case.

The chemical analyses performed on wood lying side by side along the same radius, being of the same annual rings and same position in tree, gave the following:

Per cent of rosin and phenols calculated to dry weight of wood.

	Tree No. 475.		Tree No. 476.		Average of both.	
	Treated.	Untreated.	Treated.	Untreated.	Treated.	Untreated.
Rosin:	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Sapwood	1.21	2.05	1.22	1.23	1.22	1.64
Heartwood	8.35	10.58	2.23	1.93	5.29	6.26
Phenols:						
Sapwood	0.061	0.083	0.045	0.083	0 053	0.083
Heartwood	0.290	0.180	0.070	0.058	0.180	0.119

It appears that the protective rosin is rather decreased by the treatment, and the antiseptic phenols not increased in an adequate amount to be of value since it requires at least 20 times as much heavy oil in wood impregnation to be effective. It is, however, possible that the change of color due to the process may be accomplished and be produced by the formation of empyreumatic bodies (allied to the humus substances) which may act as preservative against the attacks of fungi.

The claim that the shrinkage of the wood is favorably influenced by the process was not sustained by a series of experiments with oak and pine, which showed that the treated wood absorbs water from air or in the tub, swells and shrinks in the same manner and to about the same extent as the untreated wood.

EFFECT OF IMMERSION ON THE STRENGTH OF WOOD.

The notion frequently expressed is that "soaking wood by floating, rafting, etc., reduces its tendency to decay and shrinkage, but injures its strength." The same was claimed for boiling or steaming preparatory to bending. The last position was disproved by Peter Barlow in the first quarter of this century. The following figures (results of an experiment involving several hundred separate tests) disprove the former assertion.

The soaked wood was kept immersed six months, each piece having its check pieces from the same scantling, which were not subject to the same process, but were tested—one green and one dry. All soaked pieces were seasoned in dry kiln before testing. All values were reduced to 15 per cent moisture.

Loblolly pine.	Bending strength.	Compression strength.
	Lbs. per sq. in.	*Lbs. per sq. in.*
Soaked 6 months, and then dried	10,820	6,780
Not soaked (mean of green and dry tests)	10,570	7,060

EFFECT OF "BOXING" OR "BLEEDING."

"Bleeding" pine trees for their resin to which only the longleaf and Cuban pine are subjected—has generally been regarded as injurious to the timber. Both durability and strength, it was claimed, were impaired by this process, and in the specifications of many architects and large consumers, such as railway companies, "bled" timber was excluded. Since the utilization of resin is one of the leading industries of the South, and since the process affects several millions of dollars' worth of timber every year, a special investigation involving mechanical tests, physical and chemical analyses of the wood of bled and unbled trees from the same locality were carried out by this division. The results prove conclusively (1) that bled timber is as strong as unbled if of the same weight; (2) that the weight and shrinkage of the wood is not affected by bleeding; (3) that bled trees contain practically neither more nor less resin than unbled trees, the loss of resin referring only to the sapwood, and, therefore, the durability is not affected by the bleeding process.

The following table shows the remarkable numerical similarity between the average results for three groups of trees, the higher values of the unbled material being readily explained by the difference in weight:

Longleaf pine.	Number of tests.	Specific weight of test pieces.	Bending strength.	Compression strength.
			Lbs. per sq. in.	*Lbs. per sq. in.*
Unboxed trees	400	0.74	12,358	7,166
Boxed and recently abandoned	390	0.79	12,961	7,813
Boxed and abandoned five years	535	0 76	12,586	7,575

The amount of resin in the wood varies greatly, and trees growing side by side differ within very wide limits. Sapwood contains but little resin (1 to 4 per cent), even in those trees in which the heartwood contains abundance. In the heartwood the resin forms from 5 to 24 per cent of the dry weight (of which about

one-sixth is turpentine), and can not be removed by bleeding, so that its quantity remains unaffected by the process.

Bled timber, then, is as useful for all purposes as unbled.

STRENGTH OF LARGE BEAMS AND COLUMNS.

Owing to the fact that much wood testing has been done on small select and perfectly seasoned pieces usually from butt logs, the values thus obtained seemed to differ very markedly from the results on large timbers usually very imperfectly seasoned, and it was claimed that tests on small sizes always furnished too high values, just as if the differences were due to sizes alone.

While, to be sure, a small piece may be so selected that defects are excluded, the grain straight and in the most favorable position with regard to the load, the assumption of the difference in strength of small pieces from that of large sized sticks has never been made good experimentally.

Since it appears desirable to compare the results from large beams and columns not only with the average data obtained from the general test series on small 4 by 4 material, but also with the average strength of small pieces cut from the same beams and columns, a special inquiry into the legitimacy of such a comparison was made. This study involved over 100 separate tests and proved the very important fact, that uninjured parts of broken beams and columns do not suffer in the test. The large sized beams varied from 4 by 4 to 8 by 16 inches.

Tests of large and small beams—Bending strength.

	Small beams, general test series.	Large beams.		Small beams cut from large beams.
		Total.	Beams from which small beams were cut.	
Number of tests involved	1,986	127	57	236
	Lbs. p. sq. in.	*Lbs. p. sq. in.*	*Lbs. p. sq. in.*	*Lbs. p. sq. in.*
Longleaf	11,300	11,500	9,800	10,100
Loblolly	10,000	10,800	10,300	10,000
Shortleaf	9,300	9,200	8,700	8,700

From the preceding table it would appear that large timbers, when symmetrically cut (i. e, with the center of the log as center of the beam) develop as beams practically the same strength as the average of the small pieces, that may be cut from them and sometimes even higher values; the explanation being that cut in this manner the extreme fibers which are tested in a beam, come to lie in that part of the tree which, as a rule, contains the strongest timber.

Results discordant from these may be explained by differences in the degree of seasoning of the outer layers and also by the fact that especially in the northern pineries timbers are often cut from the top logs which are weaker and more defective.

The square columns were mostly 8 by 8 inches, some 10 by 10 inches, a few of larger and also some of smaller dimensions. The ratio of length to width varied from 12 to 27, about one-half being under and the other half over 18 to 1. The compression pieces of the regular series, and those cut from the broken columns, were in general about 4 by 4 by 6 inches.

Tests of large and small columns—compression strength.

	Regular series from same trees as the columns.	Columns, (simple compression).	Small pieces cut from columns.
Number of tests involved	949	95	97
	Lbs p sq in.	*Lbs p sq in.*	*Lbs p sq in.*
Longleaf	6 600	5,300	7,100
Loblolly	6,800	4,700	6,300
Shortleaf	5,900	4,100	6,200
Cuban	7,400	5,000	8,700

It will appear from this statement of average results that columns develop only from 62 per cent (in Cuban) to 78 per cent (longleaf) of the compression strength of ordinary short pieces. The explanation may be due to several reasons, natural and mechanical. In a column, unlike a beam, all the fibers are under great strain, hence all the defects, which are by necessity found in every column, influence the results; the flexure of a column under strain is an element of weakness, to which the short compression piece is not subject. In addition the difficulty of determining the average moisture condition of the large timber throughout the cross section and that of the small pieces cut from them afterward would render this method for columns less satisfactory; a larger number of tests will still be required to establish comparable average conditions in the two kinds of tests. It would, therefore, be unsafe to generalize too hastily from these average figures at least as to the numerical difference, for there are remarkable individual exceptions. Not only do individual columns show differences in strength 50 per cent and more lower than the compression pieces from the same log, but sometimes they show practically the same or even a higher value of strength, as will appear from the following selected cases, in which the data for the columns are placed in comparison with these obtained on compression pieces from the same tree:

Selected tests of columns and compression pieces from the same trees compared.

Number of tree.	Length.	Ratio $\frac{l}{d}$	Small pieces Average of whole tree. (*a*)	Large columns. (*b*)	Relative value. (*a*)	Relative value. (*b*)	Deflection.	Failure.
	Feet.		*Lbs. per sq in.*	*Lbs. p. sq. in.*			*Inch.*	
239	12	14	6,700	6,100	100	91	0.7	Sheared.
240	12	14	7,000	6,900	100	99	0.1	Compression.
241	12	15	6,900	6,500	100	94	0 7	Do.
309	12	12	6,800	6,500	100	96	0.4	Do.
312	12	16	6,100	6,300	100	103	0.4	Do.

In these columns (nearly one-tenth of all longleaf pine columns tested) the strength was so nearly the same as that of the short pieces, that it appears as if flexure had but little to do with the failure, the small differences being amply accounted for by a larger number of defects in the columns. Should this prove true in general for wooden columns, as ordinarily designed, the problem would become simply a study of the influence of defects and of proper inspection.

The nature of the failures would also point in this direction:

Of 86 columns 32 failed normally, *i. e.*, in simple compression; 22 were crushed near the end; 14 failed at knots, and 19 by shearing, the rupture usually beginning at or near the ends; a small knot proved sufficient to cause a large column, 20 times as long as its diameter, to fail at 14 inches from the end.

The deflection in the average for all columns (12 to 20 feet long) was only about one inch for the maximum load, when to be sure, destruction had progressed for some time; at the elastic limit the deflection was only about one half as much. These results would seem to warrant the statement that for pine columns at least, in which the ratio of height to least diameter does not exceed 1 in 20, none of the accepted column formulæ are applicable, the nature of the failure being mostly in simple compression, and depending more on specific defects than on the design of the column.

B. E. Fernow,
Chief Division of Forestry.

Approved:
J. Sterling Morton,
Secretary.

Washington, D. C., *March 6, 1896.*

Note.—The timber investigations of the Division of Forestry have for their object not only to establish reliable values of the strength of our important timber trees, but more especially to increase in general the knowledge of the properties, behavior, and economical use of wood and to furnish the data. which may lead to the formulation of rules of inspection enabling the consumer to judge the comparative value of the piece in hand, and to more carefully select and treat the material for different uses.

In addition to the tests of southern pines discussed in this circular, there have been made some 20,000 more tests in all, on white pine and Norway pine of northern growth and on the following kinds of southern growth: Bald cypress, white cedar, oaks, nine species; hickory, eight species; ash, two species; elm, two species; and red gum.

Although the number of tests for each of these kinds is not sufficient to establish the strength values with certainty, the test work has been discontinued for lack of available funds, and the accumulated data will be worked up for preliminary statement.

The publications so far issued as a result of this work are:

Bulletin 6, Timber Physics, Part I, a preliminary statement of the scope and history of timber physics and of methods pursued in these investigations. Price 10 cents.

Circulars 8 and 9, announcing results of the tests on bled and unbled longleaf pine.

Bulletin 8, Timber Physics, Part II—being an exhaustive report on the results with longleaf pine.

Bulletin 10, Timber—being a brief discussion of the characteristics and properties of wood in general with a key and list to the commercial woods of the United States. Price 10 cents.

Bulletin 12, Economical Designing of Timber Trestle Bridges—being an application of some of the results to practical problems.

These Bulletins can be had at the prices noted by application to the Superintendent of Documents, Government Printing Office, with the exception of Bulletin 8, which is out of print.

A comprehensive Bulletin on the southern pines is in manuscript, from which this Circular is extracted and a Bulletin on the principles and practice of dry kilns is in preparation.